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Interim Technical Report No. 1
April 15, 1952 - October 15, 1952

on

GALLING AND SEIZING CHARACTERISTICS OF
TITANIUM AND TITANIUM-BASE ALLOYS

to

WATERTOWN ARSENAL
Watertown 72, Massachusetts

by

William C. Leone

Contract No. DA-36-061-ORD-112
Negotiated Contract ASPR S-201
RAD Order No. TB 1-1-12045
ORD Project TB 4-15
W.A.L. Report No. 401/65-~~12~~ 13

Mechanical Engineering Department
CARNEGIE INSTITUTE OF TECHNOLOGY
Pittsburgh 13, Pennsylvania

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Interim Technical Report No. 2
April 15, 1952 - October 15, 1952

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OBJECT

A study of the seizing and galling characteristics of titanium and titanium-base alloys.

SUMMARY

Equipment for doing experimental work on friction characteristics of metals for various loads and speeds has been assembled. Tests have been made for variable conditions of load, speed, time of rubbing, and materials of rubbing specimens. Although most of the tests have been made for titanium versus titanium, many runs have been made for more commonly used metals. Plans for future work are given.

CONCLUSIONS

1. In general, at the same normal load and speed, galling will start earlier when either, or both, rubbing surface is rough.
2. For titanium vs. titanium, if galling has started on one surface it does not take long for the other surface to follow suit.
3. If the time of rubbing is made long enough almost any condition of load and speed will produce galling for titanium versus titanium.
4. In general galling occurs more easily at high loads.
5. In general galling occurs more easily at high speeds.



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Seizing and Galling of Titanium
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ABSTRACT

Interim Technical Report No. 1 covering the period from October 15, 1951 to April 15, 1952 includes a literature survey which revealed the importance of real area of contact, normal load, roughness, adhesion, adsorbed films, and temperature in friction and seizing.

In this report equipment for doing experimental work on friction characteristics for various loads and speeds is described. Typical results of tests made to date are presented. The effects on galling of load, speed, roughness, and time of rubbing are discussed. Plans for future work are given.

I. INTRODUCTION

This is the second interim technical report on the galling of titanium. The report covers the period from April 15, 1952 to October 15, 1952.

The purpose of the project is to determine the galling and seizing characteristics of titanium and titanium-base alloys. The work is to include (not necessarily be limited to) an investigation of the load and speed conditions for galling and seizing. The evaluation of friction and galling characteristics of titanium materials is to be made when they are rubbed against not only like materials but also steel and conventional bearing metals such as bronze and babbitt metal.

The materials to be studied are commercially unalloyed titanium, Ti-75A and RC-55, and two or more titanium-base alloys, such as RC-130A, RC-130B, and Ti-150A.

A future phase of this research is to make friction studies of titanium materials, with and without lubrication. It is also desirable to include a study of the effects on the friction measurements of simple heat treatments and of surface treatments specified by the Watertown Arsenal.

In the first interim technical report some of the literature on friction, wear, and seizing of metals in general was reviewed; also, results of crude tests made to give information to aid in designing the experimental apparatus were discussed.

This report presents a description of the experimental apparatus assembled for making part of the study of friction and galling characteristics of titanium. Representative results are discussed.

II. PRELIMINARY CONSIDERATIONS

Since the metals to be studied in this research are to have a wide variety of applications, it would be impossible to build one machine which would test the metals in all their uses. The very fact that all phases of field services cannot be feasibly reproduced points to the need for a fundamental study of the problem, where the operating variables can be carefully controlled and their effects analyzed.

For this purpose it is desirable to design and assemble a machine which would make possible a study of the fundamentals of friction characteristics by isolating the effects of various operating factors.

Much of the original experimental work on friction and wear was done by workers in the automotive industry. Because their interests lay chiefly in the wear and scuffing of piston rings and cylinders the apparatus used were most often of the reciprocating motion type. Even today many wear and friction tests are made on adapted shapers incorporating a Scotch Yoke motion. Tests on apparatus of this type lack means of complete control and knowledge of speed effects since the operating speed is non-uniform during a run.

Quite a few of the machines used for the evaluation of friction and wear characteristics incorporate the rubbing of a hardened steel ball against the metal to be tested. The results are valid for only the metal tested versus the hardened steel of the ball.

The apparatus described here has means by which both the speed and the material combinations to be tested are controlled. The method of rubbing the specimens is not new. However, the means of measuring the friction load is somewhat different from that used in the better known friction testing machines. The main assets of the present machine are control over a comparatively wide range of operating variables and simplicity of operation.

III. DESIGN REQUIREMENTS

The design requirements for the apparatus described here were essentially as follows:

- (1) It is possible to vary and control easily the normal load applied between the test specimens.
- (2) The relative speed of the test specimens is variable and measurable.
- (3) The specimens themselves are readily interchangeable as to materials used.

- (4) Calibration of the load measuring devices is simple.
- (5) Results can be measured accurately and recorded automatically.
- (6) Results are reproducible.
- (7) Vibrations not inherent in the rubbing process itself are eliminated.
- (8) It is possible to inspect the damaged surfaces at any time throughout each test.

IV. DESCRIPTION OF THE APPARATUS

The test apparatus is an adaptation of a small milling machine. The main components of the loading assembly can be seen in Figure 1. It provides for rubbing the end of a rod specimen against a flat sheet or plate specimen. The rod specimen is held at rest so that it traces a circular path on the flat specimen which rotates in its own plane. Means are provided for adjusting and measuring the normal force between the specimens. A ring spring is attached rigidly to the test rod holder and to a normal loading device by means of which the spring can be compressed. The compression is measured by a dial indicator. The entire normal load apparatus is attached to a carriage which can oscillate in a plane parallel to that of the plate specimen. Attached rigidly to the carriage there is an arm which at the one end impinges on a strain ring and at the other end has a dashpot for damping the oscillations. The strain ring is equipped with SR-4 strain gages. Thus the torque due to the tangential force at the "plate-rod" contact point can be determined. Since the normal load is known, the coefficient of "plate-rod" friction can be found.

Drive: The back-up plate for the flat specimen is keyed to a spindle which is motor driven. Several ranges of operating speeds are obtainable by changes in the positive drives between the motor, speed reducer, and spindle. Finer speed adjustments within each range corresponding to a given speed reducer setting are made through a rheostat on the motor.

Specimen Holders: The flat specimen is held onto the back-up plate by four holders which are essentially wedges for keeping the specimen from moving away from the back-up plate. The rod specimen is inserted in the head of the normal loading arm and is held in place by two Allen screws.

Normal Loading Device: A ring spring is attached to the rod test piece holder. A screw arrangement makes it possible to compress the ring spring and thereby impose a load between the specimens. A dial indicator measures the compression deformation of the spring from which the normal load is computed.

Lateral Loading Device: The entire normal loading device is set on a platform which rides on ball bearings and is free to move in a plane parallel to that of the flat specimen. An arm is attached rigidly to the platform so that one end rests on a steel ring. SR-4 strain gages constituting two arms of an A.C. bridge are mounted on the ring such that any deformation of the ring is indicated on a Brush Recorder tape.

Damping: A dashpot is installed on the free end of the platform arm to minimize undesirable vibrations during operation.

Support: The entire lateral loading device (which also includes the normal loading device) is mounted on the milling machine table. Thus, the standard vertical and horizontal adjustments of the milling machine can be utilized to adjust the relative positions of the specimens.

Observation of Surfaces: A low power microscope is mounted on an adjustable support so that both specimens can be inspected in place.

V. OPERATION

Calibration: Calibration of the normal loading device is made by the standard method of applying known loads and recording the displacements of the dial indicator.

There is a small platform mounted on the lateral loading arm. This provides a convenient aid for calibrating the lateral load measuring device. A Brush record is made as known weights are put on the platform.

Preparation of Specimens: After each plate specimen is checked for flatness it is rubbed with 000 emery cloth. The surface is then cleaned with carbon tetrachloride and wiped off with gauze. Finally clean carbon tetrachloride is sprayed liberally on the surface and allowed to evaporate.

A rod specimen is machined such that one end is a short 1/32 inch diameter cylinder. This is inserted in a special

holder which permits the very tip of this cylinder to be exposed and rubbed with emery cloth perpendicularly to the specimen axis. The rod end is inspected with the microscope and cleaned in a manner similar to that of the plate after which it is inspected again.

Test Run: After the plate and rod specimens are inserted in place, the milling machine table is adjusted so that there is no load between the two. The path radius of plate-rod contact is measured and the spindle speed is adjusted to give the desired relative speed at the contact point. A desired normal load is applied by means of the screw on the normal loading device. Friction of the plate on the rod will cause the platform of the lateral loading device to tilt on its ball bearings so that the end of the platform arm impinges on the strain ring. Thus the Brush Recorder indicates essentially a measure of the torque applied to the platform arm. This, in turn, is a measure of the friction force at the plate-rod contact.

At the end of one minute, which was arbitrarily chosen as the time for most of the runs, the normal load is taken off and the rod specimen is backed away from the plate. The track on the plate and the end of the rod are then inspected through the microscope. All that is required for the next run is to vertically adjust the milling machine table for a new path on the plate, adjust the speed, and install a new rod specimen.

VI. REPRODUCIBILITY TEST

An experimental apparatus is of no value unless it makes possible reproducible results for identical tests. The results of a typical reproducibility test are summarized in Figure 2.

For these tests ten rod specimens were prepared in an identical manner. One of the rods was rubbed on a clean plate with an arbitrary rod-plate contact speed of 11 feet per minute and a normal load of 0.99 lb. for one minute. Incidentally, the time of one minute is also arbitrary. For the particular tests reported here, time intervals from one to five minutes did not result in differences in the lateral load readings. It should be noted, however, that the results are valid for only the load, speed, and time intervals recorded and should not be construed to mean that other loads, speeds, and/or time intervals would give similar data. A second rod was used at another track radius

with the same peripheral speed and normal load. At the end of one minute, the normal load was increased to 1.98 lb. and a record was taken for one minute. A third rod was used at still another track radius but the speed was again adjusted to 11 feet per minute. The normal load was set at 0.99 lb. for one minute, increased to 1.98 lb. for one minute, and then increased to 2.97 lb. for one minute. Thus, the procedure was to use a clean track for each rod and to adjust for a speed of 11 feet per minute. In each case the initial normal load was 0.99 lb., which after one minute was increased to 1.98 lb., and progressively at intervals of one minute and 0.99 lb. to 10.89 lb.

In a perfectly reproducible test, the results of each run on a rod would coincide with the results of the corresponding run on all preceding rods. The curve of Figure 3 shows a composite of the results with the ten specimens. Considering the fact that many of the points on this curve are coincident and that there are unavoidable slight deviations from identity in the tests, the test of reproducibility is thought to be quite good.

In particular, the main factor which contributes to deviation from identity in the tests is that the plate specimens are of RC-55, commercially unalloyed titanium. Except for the cleaning procedure previously outlined, these plates were untreated and used as received so that their flatness would be preserved. However, close inspection under the microscope reveals the plates are not uniformly smooth. In addition, however carefully the rod specimens are prepared and installed, there is unavoidable slight deviation from true orthogonality of the rods with respect to the plate.

VII. OBSERVATION OF SURFACES

Frequent inspections of the surfaces were made under the low power microscope. The first noticeable change in the surfaces is that a shiny path appears along the rubbing circle on the plate. At first the path has no depth that can be seen, or felt with the fingers. As rubbing continues, especially if the load is increased, the path widens and deepens into a groove. Finally, the groove becomes badly torn and shows traces of powdered metal. Most of these metal particles are traceable to the plate material. However, depending upon what the rod material is, there sometimes are particles of rod material loosely adhering to the plate.

In most of the tests made both rod and plate material were commercially unalloyed titanium. In even the most badly injured surfaces there was no evidence of a Bielby layer type damage. The galled portions were more of the aforementioned powdery nature.

After the reproducibility tests previously reported, the specimens were photographed under magnification. The photographs illustrate conclusively in all cases that the damage is truly progressive in going from the first to the more heavily loaded specimens. Figure 4 shows representative specimens with increasing loads and, consequently, increasing damage.

Figure 5 shows two tracks where the load applied for track (a) is larger than that for track (b). It will be noticed that even at a lower load, track (b) is more badly damaged. In fact, a relatively large particle of adhered metal is seen on track (b). However, it can also be seen that the initial roughness of the plate for track (b), as indicated by the density of spots in the surrounding area, is greater.

It was found that, at the same normal load and speed, a rubbing circle made completely on the smoother portions of the plate took a noticeably longer time to develop into a torn and badly damaged groove than did a rubbing circle made on partly smooth and partly roughened plate material. Further proof that roughness is important is that if galling has started on one surface, it does not take long for the other surface to follow suit.

VIII. TYPICAL TEST

Figure 6 summarizes the results of eleven tests made in a manner different from the reproducibility tests. Here eleven specimens are rubbed at the same peripheral speed, but the first is used with a constant normal load of 0.33 lb., the second 0.66 lb., the third 0.99 lb., and thereafter at intervals of 0.99 lb. up to a constant normal load of 8.91 lb. Each test was of five minutes duration. The data plotted are the average values at steady state which came about no later than the second minute of operation.

This test is typical of the runs which are made for the purpose of obtaining friction data.

IX. COMMONLY USED METALS

Dry rubbing tests have been made for titanium materials and more commonly used metals. Table I shows an abstract of typical data obtained. Some of the tests indicated have not been repeated.

All of the tests indicated were made with a rod-plate contact speed of 8 feet per minute. The rods have an approximate tip diameter of 1/32 inch. Plate and rod specimens are polished as nearly as possible to the same degree of smoothness. The data given are steady values which on the average occur after the second minute. The average runs lasted about five minutes.

X. SPEED EFFECTS

Some of the effects of velocity on the coefficient of friction have been studied. Both commercially unalloyed and alloyed rods were rubbed on RC-55 plates at peripheral speeds of 3.5, 7, and 11 feet per minute. It was found that in general the coefficient of friction increases with increased velocity. The tests using the unalloyed rods substantiate this at all three speeds. However, curves of data for the alloyed rods indicate considerable scatter.

There is additional evidence that the coefficient of friction is influenced by the roughness of the surfaces. When the plate surface deteriorates it does not do so in a uniform manner. Traces of the friction load show a cyclic variation which can be positively attributed to the uneven deterioration of the plate surface.

XI. FUTURE CONSIDERATIONS

Future tests will require that the range of operating speeds be increased. For instance, the velocities used in the tests mentioned above differed by factors of only two or three. If greater factors are used, the effect on the results of inaccuracies in the contact areas will be less.

Most of the tests made to date were made at loads such that the plate was galled very soon after the start of each test. The sensitivity of the normal loading device is being increased so that tests can be made for normal loads of about 1/8 lb. to over 1 lb.

A device for measuring surface roughness is being considered for two reasons. One is to assure that the initial roughnesses of test plates are the same. The other is to aid in measuring the extent of surface damage.

XII. PERSONNEL

The personnel who have worked on this project are William C. Leone, Frederick F. Ling, Samuel Cerni, and Winston F. Lee. Professor D. W. VerPlanck has given valuable advice and criticism.

Respectfully submitted,
CARNEGIE INSTITUTE OF TECHNOLOGY

William C. Leone
William C. Leone
Research Engineer

D. W. VerPlanck
D. W. VerPlanck
Head, Department of
Mechanical Engineering

Table I. TYPICAL RESULTS

<u>MATERIALS TESTED</u>	<u>AVE. FRIC. COEFF.</u>	<u>REMARKS</u>
T4-75A rod vs. RC-55 plate	0.45	Galling of plate and rod begins under a 1 lb. load. Friction coefficient becomes higher after galling.
RC-130B rod vs. RC-55 plate	0.47	" "
T1-150 rod vs. RC-55 plate	0.47	" "
RC-130A rod vs. RC-55 plate	0.49	" "
1010 Steel rod (annealed) vs. Hot Rolled Steel plate	0.23	Loads up to 5.9 lb. were used. In the entire load range the only effects to the plate and rod are shiny spots.
1010 Steel rod vs. Babbitt plate	0.24	The Babbitt plate is visibly damaged at 0.8 lb.
Alco 17ST4 Al rod vs. Chilled Grey C.I. plate	0.40	The aluminum rod smears onto the plate at 1.5 lb.

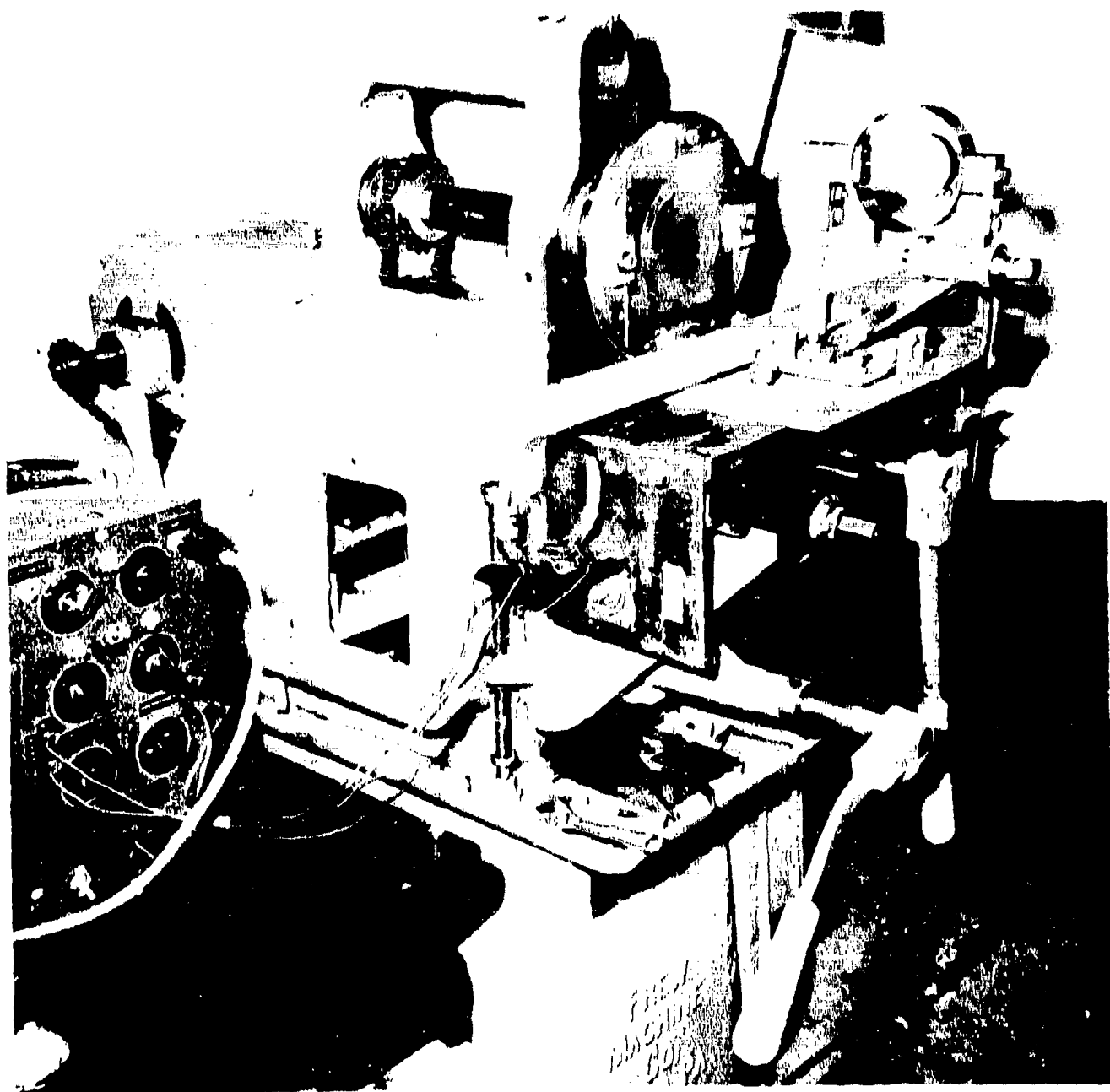


Figure 1. PHOTOGRAPH OF TEST APPARATUS

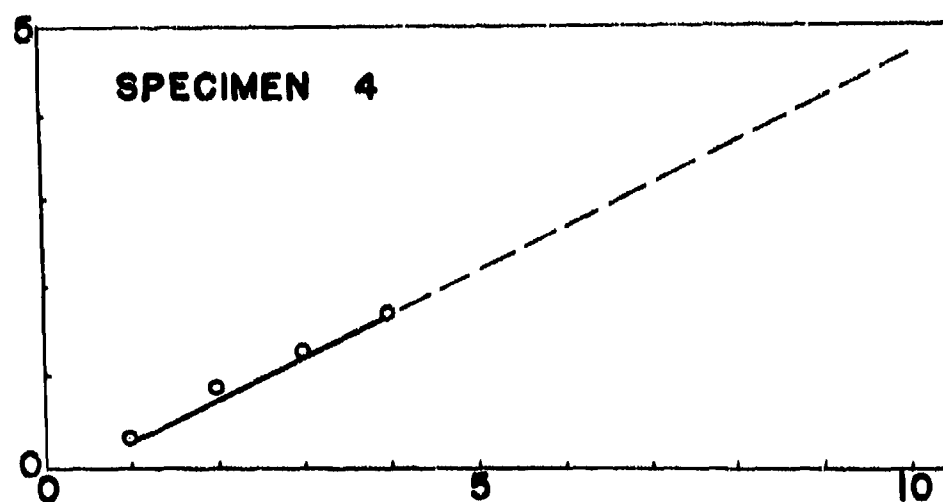
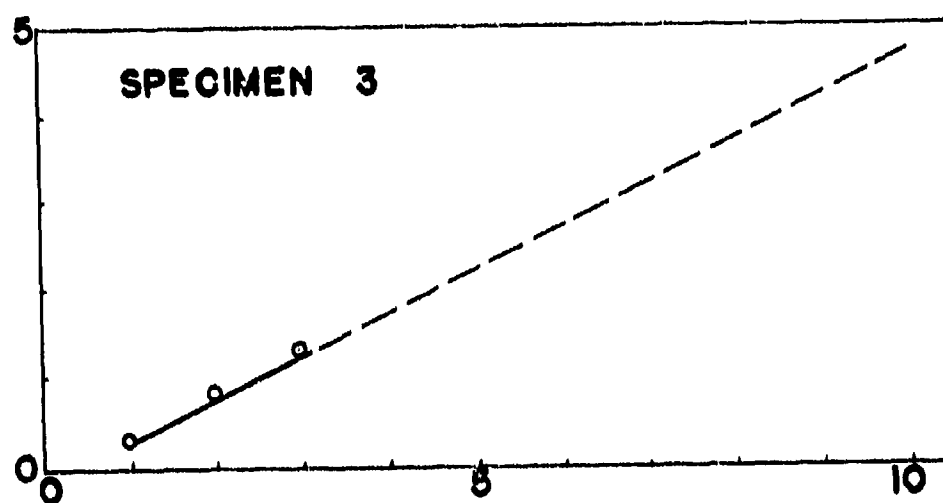
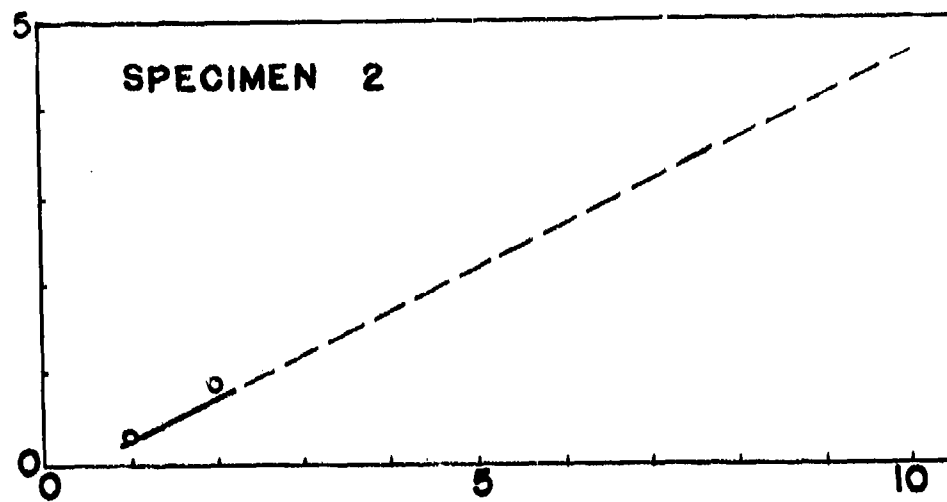


Figure 2a. REPRODUCIBILITY TEST RESULTS

Friction load vs. normal load for
T1-75A rod and RC-55 plate as described.

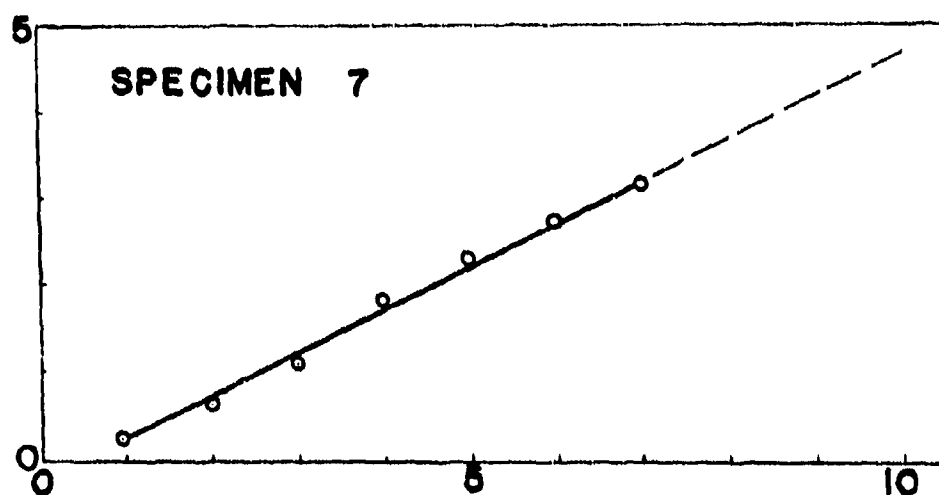
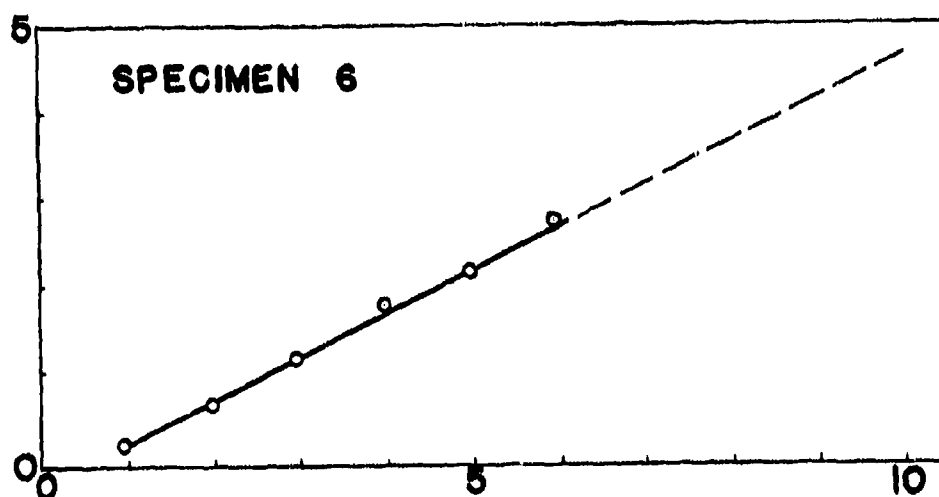
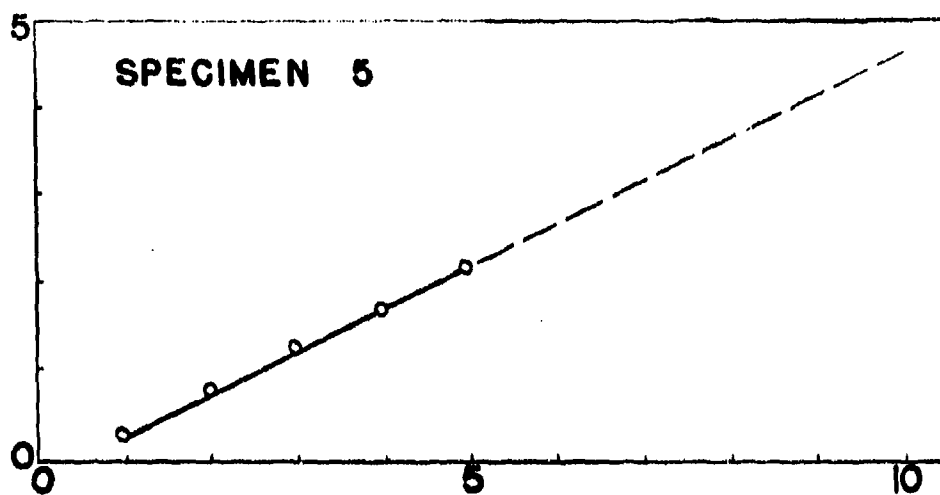


Figure 2b. REPRODUCIBILITY TEST RESULTS

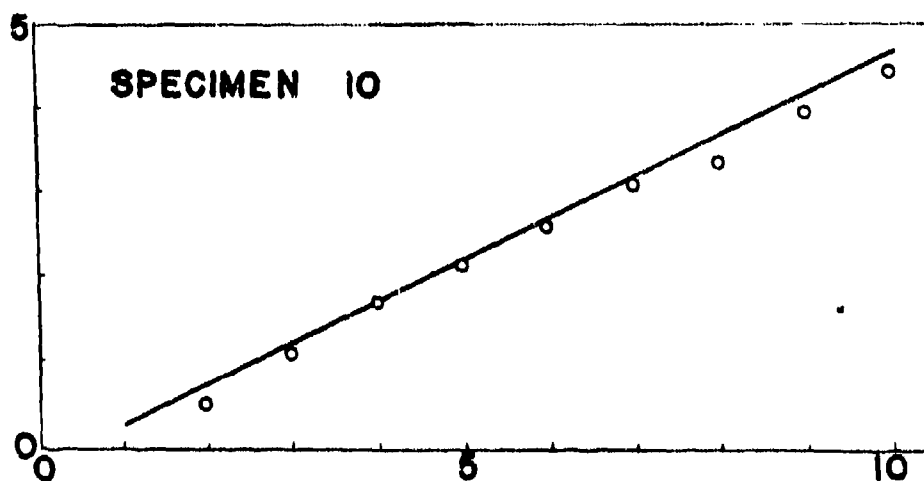
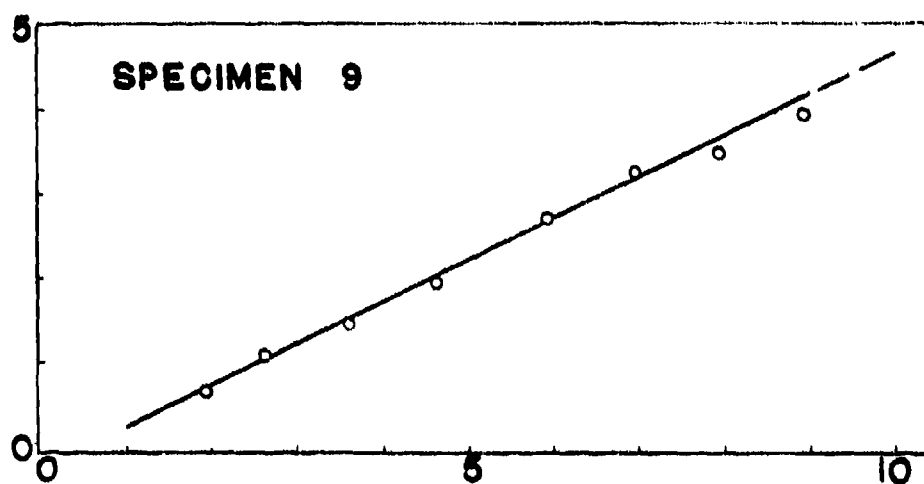
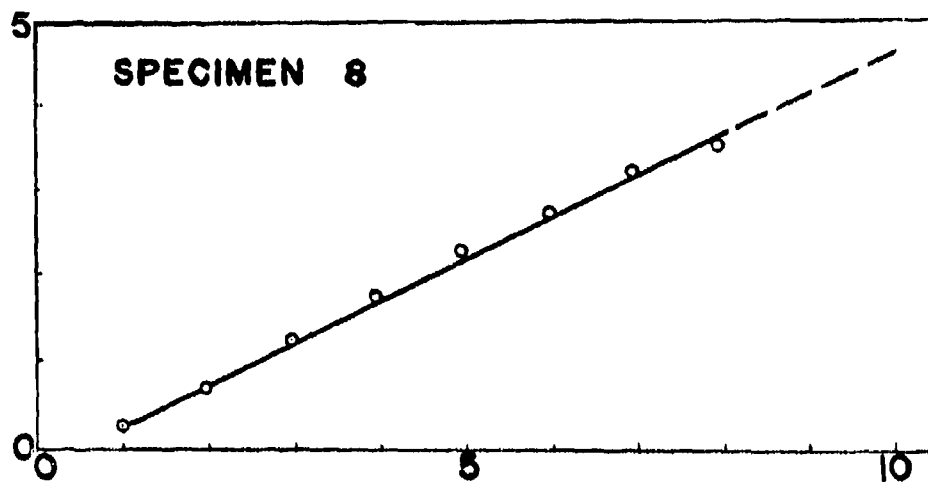


Figure 2c. REPRODUCIBILITY TEST RESULTS

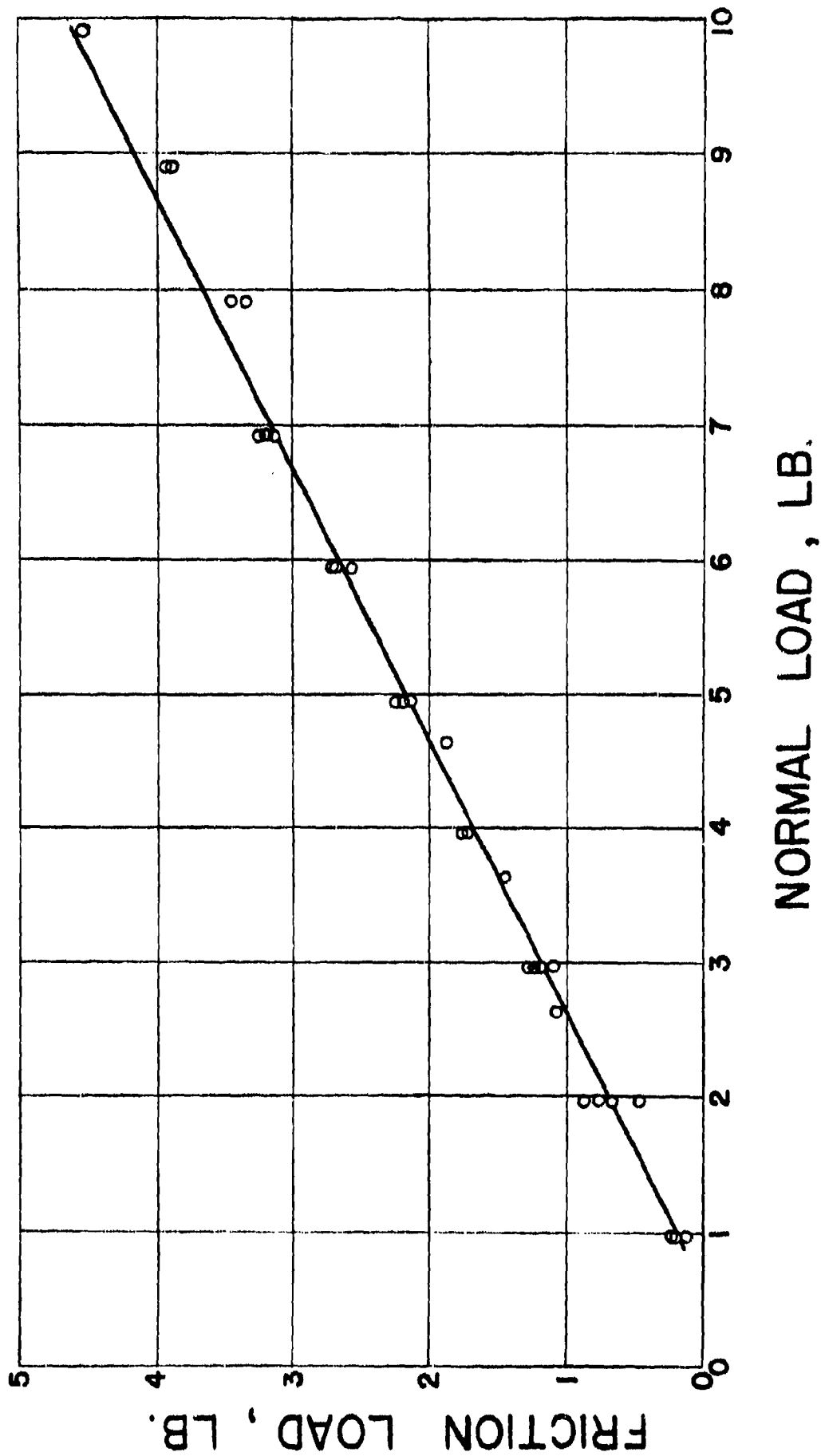


Figure 3. COMPOSITE OF PLOTS IN FIGURE 2.



(a)



(b)



(c)

**Figure 4. PHOTOGRAPHS OF ROD SPECIMENS SHOWING
 PROGRESSIVE DAMAGE WITH INCREASING LOADS**

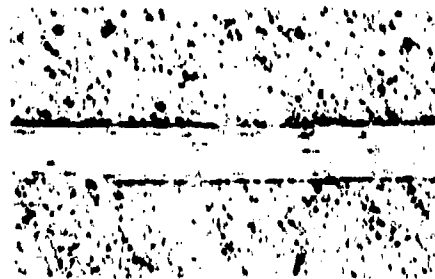


(d)

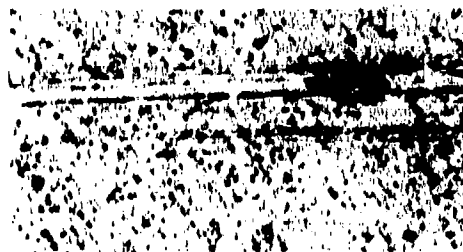


(e)

**Figure 4. PHOTOGRAPHS OF ROD SPECIMENS SHOWING
PROGRESSIVE DAMAGE WITH INCREASING LOADS**



(a)



(b)

**Figure 5. PHOTOGRAPHS OF TRACKS ON PLATE
SPECIMENS SHOWING EFFECT OF ROUGHNESS**

**The initial surface for track (a) is
less rough than that for track (b).**

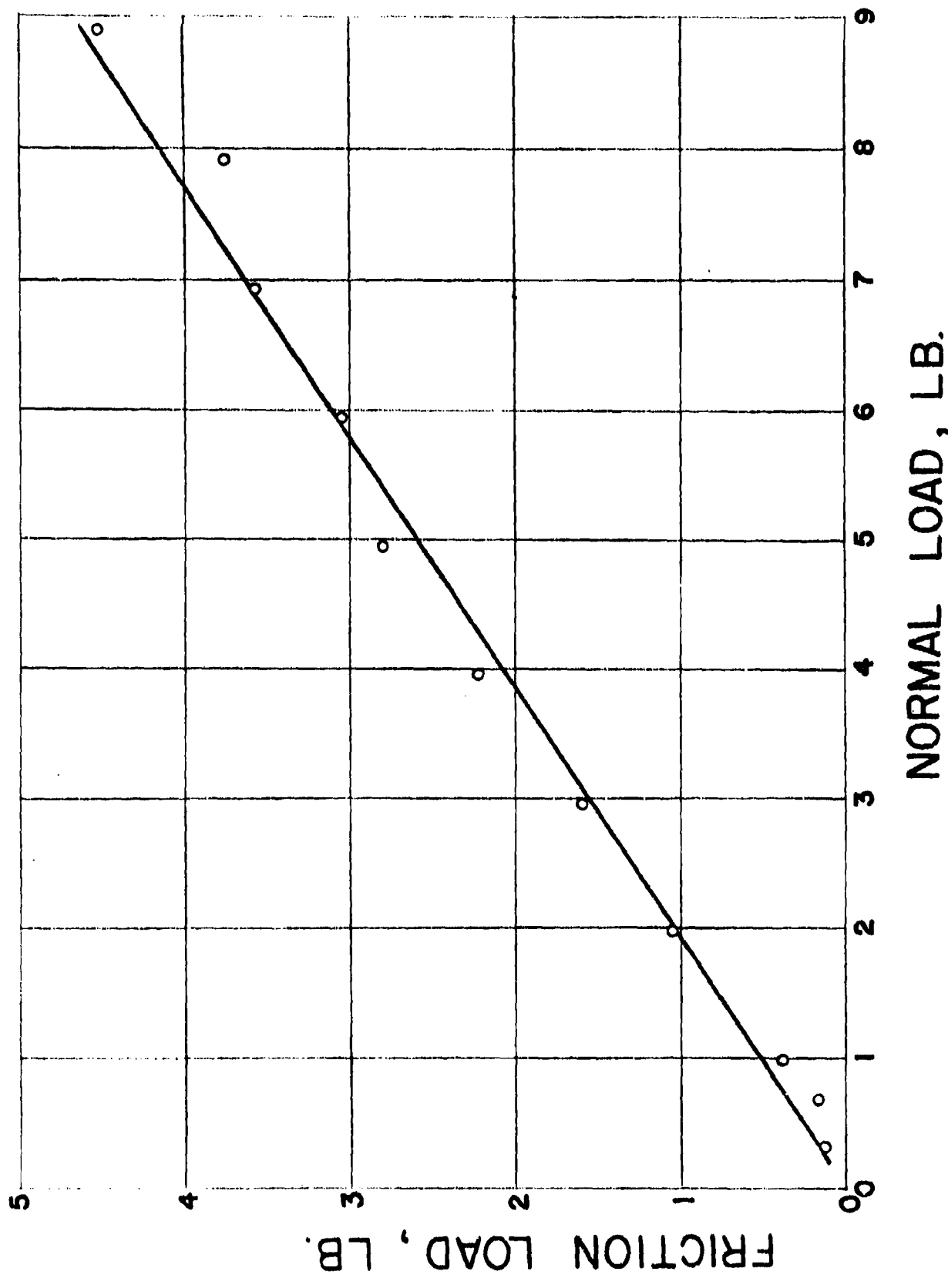


Figure 6. RESULTS OF TYPICAL FRICTION TEST